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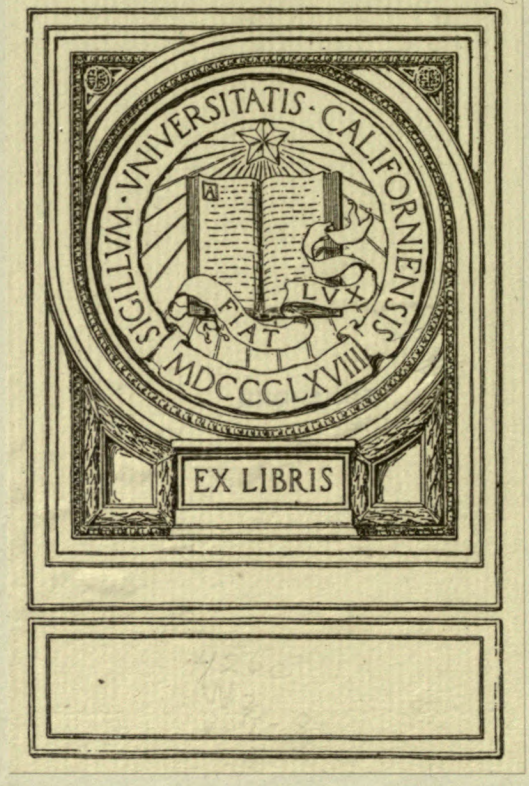
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STUDIES IN CARBOHYDRATES

THE COMPOSITION AND DIGESTIBILITY OF WHEAT BREAD AND ALLIED FOODS

GELATINIZATION OF STARCHES

BY

CHARLES H. LaWALL, Ph.M.

AND

SARA S. GRAVES, B.A.

STUDIES IN CARBOHYDRATES

MATERIALS, APPARATUS, AND METHODS

IN THE investigations herewith detailed, wheat bread, oyster, soda, and Educator crackers, pretzels, matzoth, and taka-diastase, peas, beans, lentils, and a dozen starches were used.

Acme, Freihofer, Kolb, Jones, and Sharpless breads were examined. All loaves were weighed; physical properties—texture, odor, flavor, and color—noted for the crust and interior.

The loaf and crust were crumbled separately and allowed to dry in the air. Each sample was powdered by grinding in a coffee-mill and transferred to a stoppered bottle. In the case of crackers, preliminary drying was omitted as unnecessary. They were powdered and bottled as the bread. In the composition experiments the moisture was determined in the fresh bread, loaf and crust, and in the crackers as purchased.

Acidity is expressed as lactic acid, determined by shaking 10 gm. of the material with 250 c.c. of distilled water for fifteen minutes, filtering and titrating an aliquot portion of the filtrate. A second portion was evaporated to dryness in a platinum dish, the residue being the water-soluble material.

Ash was determined by burning 2 gm. at a very low heat until white.

Salt was determined by macerating 5 gm. with 20 c.c. of water and titrating with silver nitrate, using potassium chromate as indicator.

Fat was determined by extracting 8 gm. with ether in the usual extraction tube for ten hours.

Nitrogen was determined by the Kjeldahl-Gunning method, using 3 gm., and the protein was calculated by the factor 6.25.

Total carbohydrate was determined by macerating 2.5 gm. in 10 c.c. of water in a mortar, cooling to 10° C., adding 20 c.c. of concentrated hydrochloric acid, previously cooled to 10° C., and allowing the paste to steep for thirty minutes at 20° C. The mixture was transferred to a 100 c.c. flask, 5 c.c. of a 4 per cent. solution of phosphotungstic acid were added, and made up to the mark with hydrochloric acid (sp. gr., 1.125), also cooled to 10° C. The mixture was well shaken and placed for thirty minutes in a water-bath at 20° C. After filtering and allowing to stand for fifteen minutes the filtrate

was polarized at 20° C. A comparison was then made with the polarimeter reading for 2.5 gm. of dry starch treated in a like manner.

Insoluble carbohydrate was determined after extracting the soluble carbohydrate by allowing 25 gm. to stand overnight in 100 c.c. of water, filtering washing, and treating the residue in the prescribed manner. The soluble carbohydrate was determined by difference.

The calorific values per entire loaf and per pound were calculated on the fresh bread and on the crackers as purchased.

1 pound of carbohydrate	=	1860 calories
1 pound of protein	=	1860 "
1 pound of fat	=	4220 "

Data, other than moisture and fuel value, are expressed on the dry basis.

In the digestion experiments the water-bath for keeping the mixture at constant temperature was double—a one-gallon agate pail on the outside and a two-quart tin pail suspended within. The range of temperature was not more than 1° C., and the five samples were treated at one time.

As previously stated, the ferment used was commercial taka-diastase. Four grams were dissolved in 100 c.c. of distilled water, and kept at a temperature of 55° C. for one hour, shaking every fifteen minutes. The solution was made fresh every day, and kept in a tightly stopped bottle; exactly 25 c.c. of the extract was added to 1 gm. of the bread in 50 c.c. of distilled water. The extent of the action of the diastase was determined by the amount of sugar formed, using Fehling's solution.

With this method the flasks containing the bread (loaf) and the diastase were kept stoppered and shaken every ten minutes. Digestion was allowed to continue for thirty minutes.

Then the flasks were removed from the water-bath, heated until the contents boiled to stop enzyme action, filtered, the wash-waters added to the solution, and the whole made up to the mark in a 250 c.c. flask. The solution was then tested for sugar by the following modification of a method proposed by Lintner: Into labeled test-tubes, each of 40 c.c. capacity, was run from a pipet 1 c.c. each of the two parts of Fehling's solution, different amounts of the digestion mixture (1 to 5 c.c.), and enough distilled water to make up to 15 c.c. The tubes were then plunged together into boiling water and all removed at the end of twenty minutes.

The amount of the given sugar solution needed to reduce 2 c.c. of Fehling's

solution was ascertained by comparison, after three or four hours' standing; when the last of the blue color could be recognized, a check was made with potassium ferrocyanid solution. The end point under these conditions corresponded to 0.008 gm. of maltose for 2 c.c. of Fehling's solution.

Correction was made for the amount of moisture in the bread and the result expressed as per cent.

EXPERIMENTS WITH STARCH

Preliminary experiments were made with raw starch, starch cooked below and at the boiling temperature, starch as found in bread, crackers, peas, beans, and lentils. In each case microscopic examination was made. Experiments were also made to determine the gelatinization points of some starches.

1. RAW STARCH.—In this experiment potato, sago, sweet potato, tapioca, wheat, buckwheat, oat, rice, barley, pea, and bean starches were studied under the microscope, with and without polarized light and selenite plates, and with water, chloral hydrate, and glycerol as mounting media. (See Table 1.)

TABLE 1.—EXAMINATION OF RAW STARCHES IN WATER, CHLORAL SOLUTION OR GLYCEROL.

SOURCE	HILUM	RINGS	FORM	WITH POLARIZER	
				Without Selenite	With Selenite
Potato	Central dot.	Complete and distinct.	Ovate.	Crosses well marked.	Colors brilliant.
Maranta	Circle or line often cracked.	Complete and fairly distinct.	Ovate.	Crosses well marked.	Colors brilliant.
Sago	Cleft or dot.	Faint.	Oval and truncated.	Crosses well marked.	Colors brilliant.
Tapioca	Central dot or cleft.	Invisible.	Round or kettle drum.	Crosses well marked.	Colors brilliant.
Sweet potato	Dot.	Invisible.	Round or bell-shaped.	Crosses well marked.	Colors faint.
Corn	Dot, cleft or cross.	Almost invisible.	Round or polygonal.	Crosses faint.	Colors faint.
Wheat	Indistinct.	Indistinct.	Round or oval.	Crosses faint.	Colors faint.
Buckwheat	Central dot or cleft.	Invisible.	Polygonal, often compound.	Crosses well marked.	Colors faint.
Oat	Faint.	Faint.	Polygonal and a few spherical.	Crosses very faint.	Colors very faint.
Rice	Cleft or central dot.	Invisible.	Hexagonal, some triangular.	Cross well marked.	Colors marked.
Barley	Cleft or central dot.	Faint.	Round or ovate.	Cross faint.	Colors faint.
Pea and bean	Furrow.	Distinct.	Oval or reniform.	Cross well marked.	Colors marked.

2. Cooked Starch.—Below and at the boiling temperature. The same starches were used as in the previous tests. That the transition from the raw to the swollen stage might be observed with the microscope the pastes were made with cold water and gradually raising the temperature in the double water-bath. The pastes were observed at 37°, 80°, and 100° C., and after remaining at 37°, 80°, and 100° C. for thirty minutes. It was noticed that the absorption of water begins at the hilum, working toward the edge until the granules burst or collapse. (See Table 2.)

TABLE 2.—STARCH COOKED BELOW AND AT BOILING-POINT.

Starch	37°	80°	100°	37°, Thirty Minutes	80°, Thirty Minutes	100°, Thirty Minutes
Potato.....	Unchanged.	Swollen and broken.	White field.	Many swollen.	A few swollen and broken in white field.	White field.
Maranta....	Unchanged.	Swollen and broken.	White field.	..	White field.	White field.
Sago.....	Unchanged.	Swollen and broken.	A few broken in white field.	Many swollen.	White field.	White field.
Tapioca....	Unchanged.	Swollen and broken.	White field.	Many swollen.	A few broken in white field.	White field.
Sweet potato	Unchanged.	Swollen and broken.	A few broken in white field.	Many swollen.	A few broken in white field.	White field.
Corn.....	Unchanged.	Swollen and broken	White field.	A few swollen.	All broken and swollen.	White field.
Wheat.....	Unchanged.	Swollen and broken.	White field.	A few swollen.	All broken and swollen.	White field.
Buckwheat..	Unchanged.	Swollen and broken.	White field.	Many swollen.	All broken and swollen.	White field.
Oat.....	Unchanged.	Swollen and broken.	White field.	..	..	..
Rice.....	Unchanged.	Swollen and broken.	White field.	A few swollen.	White field.	White field.
Barley	Unchanged.	Swollen and broken.	White field.	A few swollen.	All broken and swollen.	White field.
Pea and bean	Unchanged.	Swollen and broken.	White field.	Many swollen.	All broken and swollen.	White field.

3. Starch in Bread and Crackers.—In these experiments wheat, rye, graham and gluten bread, rolls, oyster crackers, pretzels, and matzoth were examined under the microscope, with and without polarized light, noting the condition of the starch.

4. Starch in Cooked Vegetables.—Microscopic examinations were made. In these experiments microscopic examinations were made of the starch in beans, peas, and lentils, boiled until soft, in baked beans and string-beans

as served for food, and in petits pois, canned. In every case the starch granules were found to be entirely gelatinized, either swollen or broken.

TABLE 3.—STARCH IN BREAD AND CRACKERS.

Source	Structure	Granules	With Polarizer	
			Without Selenite	With Selenite
Bread (wheat), Acme, Kolb, Freihofer, and Sharpless.	Lines between gluten and starch distinct.	Swollen and massed, some broken.	No effect.	No effect.
Bread (rye)	Gluten dark and massed with bran.	Swollen and massed, some broken.	No effect.	No effect.
Bread (graham)	Gluten dark and massed with bran.	Swollen and massed, some long and narrow granules.	No effect.	No effect.
Bread (gluten)	No distinct line between gluten and starch.	Many swollen starch granules.	No effect.	No effect.
Rolls	Like wheat bread.	Like wheat bread.	No effect.	No effect.
Exton Crackers	..	Many swollen and broken.	..	..
Sunshine Oyster Crackers.	..	Many grains swollen, some grains broken.	No effect.	No effect.
Pretzels	..	Many swollen and broken.	No effect.	No effect.
Matzoth	..	A few broken and swollen—most grains unchanged.	Cross distinct.	Colors distinct.

5. Gelatinization Points.—For these experiments a triple water-bath of three beakers was used. The heat was applied gradually, stirring the paste constantly. One gram of the starch was made into a paste with 100 c.c. of distilled water. A drop of the paste was removed at each degree and viewed with the microscope. The point at which double refraction disappeared in the majority of the granules was taken as the point of gelatinization. (See Table 4.)

TABLE 4.—GELATINIZATION POINTS OF FREE STARCH.

Potato (dried)	65°–66°
Potato (raw)	58°–59°
Maranta	70°–71°
Sago	70°–71°
Tapioca	uncertain
Sweet Potato	70°–71°
Corn	70°–71°
Wheat (dried)	59°–60°
Wheat (flour)	59°–60°
Pea and bean	63°–64°

Gelatinization of Pea, Bean, and Lentil Starches.—In these experiments the conditions were as above, except that the paste was made with 1 gram of raw

peas, beans, or lentils. All samples were crushed in a coffee-mill, but resulting powder differed as to fineness. Seven varieties of bean, four varieties of peas, and one variety of lentil were examined. (See Table 5.)

TABLE 5.—GELATINIZATION POINTS OF STARCHES IN PLACE.

Bean	Pea	74°
	Red kidney	74°
	Marrow	71°
	Black	72°
	French lima	71°
	Lima	80°
Lentil		74°
Pea	Yellow split	70°
	Green split	70°
	Green	74°
	Black-eye	70°

Noting the gelatinization points of raw and dried potato starch, and the diverse results in the pea and bean experiments, it is evident that the form of the starch and size of the particles have marked influence. It is possible that the time required to heat to the desired point may affect the result. The greatest difficulty, however, lies in determining the point at which the majority of the granules may be called gelatinized. It is not definite within one to three degrees.

As a means of distinguishing starches in a mixture the method appears useless, especially with the small granule starches, such as wheat and rye, in which the refraction is at all times very faint.

COMPOSITION OF WHEAT BREAD AND CRACKERS

INTERIOR OF LOAF.—In this experiment Acme, Freihofer, Kolb, Sharpless, and Jones breads were used. The methods, as previously stated, were applied, and all results, unless otherwise marked, are expressed on a dry basis. (See Table 6.)

TABLE 6.—INTERIOR OF LOAF.

	Moisture	Acidity	Ash	Fat	Salt	N.	6.25 N.	Soluble Carbohydrates	Insoluble Carbohydrates	Ratio of Total to Soluble Carbohydrates	Watery Extract	Calorific Value per Pound, Fresh
Acme	38.07	0.26	1.82	3.28	1.78	2.06	12.87	4.7	68.1	6.4	15.59	1073.76
Freihofer	38.2	0.32	2.39	2.27	2.08	2.20	13.75	3.7	64.8	5.4	15.55	1004.02
Kolb	37.7	0.35	1.99	2.88	1.86	2.38	14.87	3.9	67.0	5.5	16.93	1069.69
Sharpless	40.4	0.24	2.59	1.44	2.07	2.31	14.23	4.7	64.5	6.7	11.94	961.07
Jones	36.2	0.22	2.3	2.95	2.0	2.12	13.25	4.7	58.5	7.4	12.45	986.65

CRUST.—The conditions were as above. (See Table 7.)

TABLE 7.—CRUST.

	Moisture	Acidity	Ash	Fat	Salt	N.	Protein	Soluble Carbohydrates	Insoluble Carbohydrates	Ratio of Total to Soluble Carbohydrates	Watery Extract	Calorific Value per Pound, Fresh
Acme	18.3	0.46	1.79	2.91	1.74	2.19	13.68	12.24	61.2	16.66	15.99	1423.41
Freihofer	17.0	0.42	2.37	1.28	2.11	2.32	14.50	10.67	61.54	14.77	16.41	1383.46
Kolb	21.2	0.45	1.97	1.53	1.64	2.36	14.75	7.89	56.84	10.64	13.63	1215.79
Sharpless	21.0	0.42	2.30	1.51	1.99	2.35	14.68	12.58	56.89	18.1	12.50	1284.74
Jones	19.1	0.28	1.87	3.81	1.45	2.17	13.56	6.51	61.21	9.61	11.47	1359.31

A sample of Home-made bread prepared with a patent mixer of the ordinary type was examined. The microscopic appearance of the starch granules was similar to that observed in the commercial samples. The analysis was as follows:

TABLE 8.—HOME-MADE BREAD.

	Moisture	Acidity	Ash	Fat	Salt	N.	6.25 N.	Soluble Carbohydrates	Insoluble Carbohydrates	Ratio of Total to Soluble Carbohydrates	Watery Extract	Calorific Value Per Pound, Calories
Loaf	36.18	0.17	1.94	2.83	1.43	1.86	11.62	7.8	63.35	10.9	10.85	1043.01
Crust	19.2	0.21	2.39	4.78	1.87	1.89	11.81	9.53	62.84	13.1	12.1	1437.69

Calorific value per loaf, 1540.9

Flavor.—Sweet and nutty.

Texture.—Coarse honeycomb, elastic, but somewhat crumbly. Crust light brown; loaf yellowish. (Table 8.)

CRACKERS.—In this experiment Sunshine and Exton oyster crackers, Uneeda biscuit (soda crackers), Educator crackers, matzoth, and pretzels were used. The conditions were as above.

TABLE 9.—SAMPLES OF CRACKERS.

	Moisture	Acidity	Ash	Fat	Salt	N.	6.25 N.	Soluble Carbohydrates	Insoluble Carbohydrates	Ratio of Total to Soluble Carbohydrates	Watery Extract	Calorific Value per Pound as Purchased
Sunshine	5.87	0.07	2.11	6.83	1.63	1.78	11.12	5.57	64.53	7.94	6.54	1852.21
Exton	4.57	0.11	0.8	9.06	0.78	1.91	11.94	5.50	66.8	7.60	5.91	1860.13
Educator	2.03	0.24	1.71	7.64	1.66	1.81	11.31	7.64	65.27	10.47	10.1	1860.35
Uneeda	5.36	0.04	2.12	9.06	1.46	1.71	10.68	6.34	72.9	8.0	7.29	1944.71
Pretzels	7.56	0.28	2.88	0.35	2.78	1.33	8.31	8.12	64.9	11.12	10.96	1412.06
Matzoth	2.05	0.13	0.49	0.51	1.54	1.54	9.62	4.6	79.62	5.4	5.2	1730.74

In Table 1 the very slight differences in factors are noticeable. The ash differences are negligible; the amounts of salt and fat seem to depend entirely on the mood of the bread-maker; the protein differences are slight, as might be expected in bread made from the same kind of flour. The factors on which the value of the bread depend are the soluble and insoluble carbohydrates, and here again the difference between the breads is so small as to be no cause for saying one make of bread is superior to another. If it was possible to distinguish, Jones' bread would rank first, and Sharpless second, on the soluble carbohydrate basis, but on the calorific value Sharpless' bread is the lowest of the five. The same remark may be made about the crusts and crackers, the percentages of soluble carbohydrates are larger on account of the greater heat applied in baking, the calorific values are greater because of the smaller amount of water, and in the crackers the larger amount of fat. If taste was not one of the prime factors in digestion, it would be advisable, for fuel value, to eat pretzels rather than bread. It is not unlikely that different samples of the same makes would show a reversal of the apparent differences.

Digestion Experiment.—In this experiment the interior of the loaf was used. One gram to 25 c.c. of taka-diastase solution. The pastes after digestion were tested with Fehling's solution and the following results were obtained. (Table 10.)

TABLE 10.—DIGESTIBILITY OF CARBOHYDRATES OF BREAD.

	Per Cent. Carbohydrates	Per Cent. Maltose	Per Cent. Carbohydrates Digested
Acme	72.8	67.9	93.2
Freihofer	68.5	64.3	93.8
Kolb	70.9	66.8	94.2
Sharpless	69.2	64.3	92.9
Jones	63.2	61.1	96.6
Average			94.1

In applying the results of this experiment it must be remembered that the digestibility of the carbohydrate only is considered. It would be expected that the percentage of carbohydrates digested would differ as the amount of soluble starch. However, the object was not to obtain exact figures, but comparative results. The method used was not applicable otherwise, for 0.1 c.c. of the sugar solution (1 gm. of bread in 250 c.c.) makes an imperceptible difference in the copper tint, but permits a range of 4 per cent. in the result.

DEDUCTIONS AND CONCLUSIONS

The microscopic examination of starch, both raw and after cooking, has shown that in process of bread-making it undergoes a marked change which has a direct effect on the composition and value of the bread produced. From 5 to 8 per cent. of the insoluble starch is changed to a soluble form, and very many grains are ruptured and rendered more susceptible to the action of solvents, such as the digestive fluids, by combined action of heat and ferments. The 35 to 40 per cent. of water prevents the temperature in the interior of the loaf from rising much above 100°, thus accounting for the small amount of soluble starch in comparison with the 10 to 18 per cent. in bread-crust and 5 to 12 per cent. in crackers.

With the modern process of bread-making on the large scale it is evident that differences in methods or in constituents make only a very slight difference in products, and that claims of superiority, other than on the basis of taste, are untenable.